AFRL-OSR-VA-TR-2013-0170

QuEST: Robust Quantum Gadgets

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02/28/2013
Final Report

REPORT DOCUMENTATION PAGE

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1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
02/28/2013	Final Progress Report	12/01/11 - 11/30/12

4. TITLE AND SUBTITLE
QuEST: Robust Quantum Gadgets

5a. CONTRACT NUMBER
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5b. GRANT NUMBER
FA9550-09-1-0044

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Aram Harrow

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of Washington
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8. PERFORMING ORGANIZATION REPORT NUMBER
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9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
USAF AFRL
AF Office of Scientific Research
875 North Randolph Street, Room 3112
Arlington, VA 22203

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12. DISTRIBUTION/AVAILABILITY STATEMENT
DISTRIBUTION A: Distribution approved for public release.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

That quantum computation is a realistic model of computation rests heavily upon the legs of the threshold theorem for fault-tolerant quantum computation. This theorem tells us roughly that, if noise is weak enough and quantum control is strong enough, then robust quantum computation is possible with the added overhead of using more qubits and more time spent performing quantum gates. These added resources scale efficiently with the desired accuracy of the quantum computation and yet, because a theorem is not a technology, the quantum computing community is technically far from achieving the break-even point for these methods. Here we propose revolutionary ideas in fault-tolerant quantum computing which will jump-start the building of a quantum computer. Among the threads in our approach are the construction of small scale gadgets for energetic protection of quantum information, the construction of novel and robust perturbation theory gadgets, the construction of scalable stabilizer Hamiltonians, and methods for achieving the fault-tolerant adiabatic quantum computation.

15. SUBJECT TERMS
fault-tolerant adiabatic quantum computation; self-correcting quantum system; robust perturbation theory gadgets

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Aram Harrow
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INSTRUCTIONS FOR COMPLETING SF 298

1. REPORT DATE. Full publication date, including day, month, if available. Must cite at least the year and be Year 2000 compliant, e.g. 30-06-1998; xx-06-1998; xx-xx-1998.

2. REPORT TYPE. State the type of report, such as final, technical, interim, memorandum, master's thesis, progress, quarterly, research, special, group study, etc.

3. DATES COVERED. Indicate the time during which the work was performed and the report was written, e.g., Jun 1997 - Jun 1998; 1-10 Jun 1996; May - Nov 1998; Nov 1998.

4. TITLE. Enter title and subtitle with volume number and part number, if applicable. On classified documents, enter the title classification in parentheses.

5a. CONTRACT NUMBER. Enter all contract numbers as they appear in the report, e.g. F33615-86-C-5169.

5b. GRANT NUMBER. Enter all grant numbers as they appear in the report, e.g. AFOSR-82-1234.

5c. PROGRAM ELEMENT NUMBER. Enter all program element numbers as they appear in the report, e.g. 61101A.

5d. PROJECT NUMBER. Enter all project numbers as they appear in the report, e.g. 1F665702D1257; ILIR.

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6. AUTHOR(S). Enter name(s) of person(s) responsible for writing the report, performing the research, or credited with the content of the report. The form of entry is the last name, first name, middle initial, and additional qualifiers separated by commas, e.g. Smith, Richard, J, Jr.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES). Self-explanatory.

8. PERFORMING ORGANIZATION REPORT NUMBER. Enter all unique alphanumeric report numbers assigned by the performing organization, e.g. BRL-1234; AFWL-TR-85-4017-Vol-21-PT-2.

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES). Enter the name and address of the organization(s) financially responsible for and monitoring the work.

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13. SUPPLEMENTARY NOTES. Enter information not included elsewhere such as: prepared in cooperation with; translation of; report supersedes; old edition number, etc.

14. ABSTRACT. A brief (approximately 200 words) factual summary of the most significant information.

15. SUBJECT TERMS. Key words or phrases identifying major concepts in the report.

16. SECURITY CLASSIFICATION. Enter security classification in accordance with security classification regulations, e.g. U, C, S, etc. If this form contains classified information, stamp classification level on the top and bottom of this page.

17. LIMITATION OF ABSTRACT. This block must be completed to assign a distribution limitation to the abstract. Enter UU (Unclassified Unlimited) or SAR (Same as Report). An entry in this block is necessary if the abstract is to be limited.

AFOSR #FA9550-09-1-0044
"QuEST: Robust Quantum Gadgets"
Pis: Aram Harrow (formerly Dave M. Bacon)
Final Report

Accomplishments for 2011-13:

We have continued our work on making stabilizer codes local and have analyzed the distance properties of the resulting codes. This allows existing schemes for fault-tolerant quantum computing to be transformed into spatially local quantum error-correcting codes with distance scaling like a power of the number of qubits. We have extended this work as well to give constructions which are low-weight but not spatially local. This gives a generic prescription for turning any code into one with low-weight generators while preserving the distance. As a result, we can connect two major open problems in quantum error correction: (1) whether there exist codes with linear distance and sublinear-weight generators, and (2) whether there exist codes with constant-weight generators and distance scaling better than the square root of the number of qubits. A corollary of our work is that a positive answer to (1) would imply a positive answer to (2).

An additional accomplishment is to develop a method for testing large entangled states using only a constant amount of communication. Previous work required an amount of communication that grew with the size of the entangled states.

Publications for 2011-12:

S. T. Flammia, A. W. Harrow and J. Shi. "Local Embeddings of Quantum Codes" in preparation, 2013.

A. W. Harrow. "Testing Entanglement with a Constant Amount of Communication," in preparation, 2013.

AFOSR Deliverables Submission Survey

Response ID: 2371 Data

1.

Report Submission Form

If you have any questions, please contact your Program Manager or Assistant Program Manager.

Air Force Office of Science and Research
875 Randolph Street
Suite 325 Room 3112
Arlington, VA 22203

1. Report Type

Final Report

4. Primary Contact E-mail
Contact email if there is a problem with the report.

melody@cs.washington.edu

5. Primary Contact Phone Number
Contact phone number if there is a problem with the report

206.616.1068

6. Organization / Institution name

University of Washington

Award Information

8. Grant/Contract Title
The full title of the funded effort.

QuEST: Robust Quantum Gadgets

9. Grant/Contract Number
AFOSR assigned control number. It must begin with "FA9550" or "F49620".

FA9550-09-1-0044

10. Principal Investigator Name
The full name of the principal investigator on the grant or contract.

Aram Harrow

11. Program Manager
The AFOSR Program Manager currently assigned to the award

Tatjana Curcic

Report Information - Annual Report

Report Information - Final Report

Report Information - Conference/Workshop Report

Report Information - Equipment Report

Report Information - Patent/Invention Report, DD882

Report Information - Financial Report, SF425

Report Information - STTR Status Report

Report Information - STTR Annual Progress Report

For an annual report, the reporting period start date is either start date of the grant, if this is the first report, or 1 day after the due date of the previous report. The end date is due date of this report.

The reporting period start and end dates are the start and end dates of the award.

22. Reporting Period Start Date

12/01/2011

23. Reporting Period End Date

11/30/2012

Report Abstract:

In the Abstract section, please list any accomplishments that have been made since the last report submission (or since the beginning of the award if this is the first report).
Please do not type "see report" here, include at least an abstract, 250 words or more, of the accomplishments mentioned in your report.

Report Abstract:

In the Abstract section, enter the Final Conference Report. This is a summary of all scientific papers presented and a list of all attendees.

Report Abstract:

In the Abstract section, enter the Final Performance Report.

The Final Performance Report will identify the acquired equipment (although it may vary from that described in your proposal) by name and associated costs. The Final Performance Report shall summarize the research or educational project for which the equipment will be used.

The patent and inventions coverage contained in Article 36, Intangible Property, of the Research Terms and Conditions does not apply to this award.

Article 15, Intangible Property, in the AFOSR Agency Specific Requirements does not apply to this award.

27. Abstract

We have continued our work on making stabilizer codes local and have analyzed the distance properties of the resulting codes. This allows existing schemes for fault-tolerant quantum computing to be transformed into spatially local quantum error-correcting codes with distance scaling like a power of the number of qubits. We have extended this work as well to give constructions which are low-weight but not spatially local. This gives a generic prescription for turning any code into one with low-weight generators while preserving the distance. As a result, we can connect two major open problems in quantum error correction: (1) whether there exist codes with linear distance and sublinear-weight generators, and (2) whether there exist codes with constant-weight generators and distance scaling better than the square root of the number of qubits. A corollary of our work is that a positive answer to (1) would imply a positive answer to (2).

An additional accomplishment is to develop a method for testing large entangled states using only a constant amount of communication. Previous work required an amount of communication that grew with the size of the entangled states.

28. Distribution Statement

This is block 12 on the SF298 form.

Distribution A - Approved for Public Release

29. Explanation for Distribution Statement

If this is not approved for public release, please provide a short explanation. E.g., contains proprietary information.

NOTE: Extra documentation is NOT required for this report. If you would like to send additional documentation, send it directly to your Program Manager or Assistant Program Manager.

31. SF298 Form

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Additional Information

35. Archival Publications (published) during reporting period:

S. T. Flammia, A. W. Harrow and J. Shi. "Local Embeddings of Quantum Codes," in preparation, 2013.

A. W. Harrow. "Testing Entanglement with a Constant Amount of Communication," in preparation, 2013.

36. Changes in research objectives (if any):

37. Change in AFOSR Program Manager, if any:

38. Extensions granted or milestones slipped, if any:

A one-year no-cost extension was granted via AFOSR Modification #P00008. The new end date for this grant was 30 November 2012.

For an STTR Status or STTR Annual Progress Report, please e-mail your program manager directly.

2. Thank You

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Principal Investigator Name:	Aram Harrow
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Primary Contat Phone Number:	206.616.1068
Grant/Contract Title:	QuEST: Robust Quantum Gadgets
Grant/Contract Number:	FA9550-09-1-0044
Program Manager:	Tatjana Curcic
Report Type:	Final Technical
Reporting Period Start Date:	12/01/2011
Reporting Period End Date:	11/30/2012
Abstract:	We have continued our work on making stabilizer codes local and have analyzed the distance properties of the resulting codes. This allows existing schemes for fault-tolerant quantum computing to be transformed into spatially local quantum error-correcting codes with distance scaling like a power of the number of qubits. We have extended

this work as well to give constructions which are low-weight but not spatially local. This gives a generic prescription for turning any code into one with low-weight generators while preserving the distance. As a result, we can connect two major open problems in quantum error correction: (1) whether there exist codes with linear distance and sublinear-weight generators, and (2) whether there exist codes with constant-weight generators and distance scaling better than the square root of the number of qubits. A corollary of our work is that a positive answer to (1) would imply a positive answer to (2).

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Distribution Statement:	Distribution A - Approved for Public Release
SF298 Form:	55-c5e67c413ec7fcd8965d6f9d76a15893_SF298final.pdf
Report Document	52-40ea215929afe1827ed9503da4a2aac4_final2download.pdf
Archival Publications:	S. T. Flammia, A. W. Harrow and J. Shi. "Local Embeddings of Quantum Codes," in preparation, 2013. A. W. Harrow. "Testing Entanglement with a Constant Amount of Communication," in preparation, 2013.
Changes in Research objectives:	
Change in AFOSR Program Manager, if any:	
Extensions granted or milestones slipped, if any:	A one-year no-cost extension was granted via AFOSR Modification #P00008. The new end date for this grant was 30 November 2012.

Response Location

Country:	United States
Region:	WA
City:	Seattle
Postal Code:	98195
Long & Lat:	Lat: 47.432301, Long:-121.803398